The Trend Depends on the Statistic

Examples from Ozone and PM Measurements in Central California

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Introduction

Tracking progress in reducing air pollution is a key component of air quality planning. Policy makers need to know how close their area is to meeting air quality standards and how fast progress (or regress) is being made. We demonstrate here that the rate of progress depends on which statistic is used.

Often multiple standards exist for a given pollutant and multiple statistics to apply to them. For example, there are both 24-hour and annual PM2.5 standards. And progress toward the 24-hour standard can be measured either by the design value or by the number of times the standard is exceeded. We may be interested in trends in other facets of the distribution also, such as different percentiles and exposure.

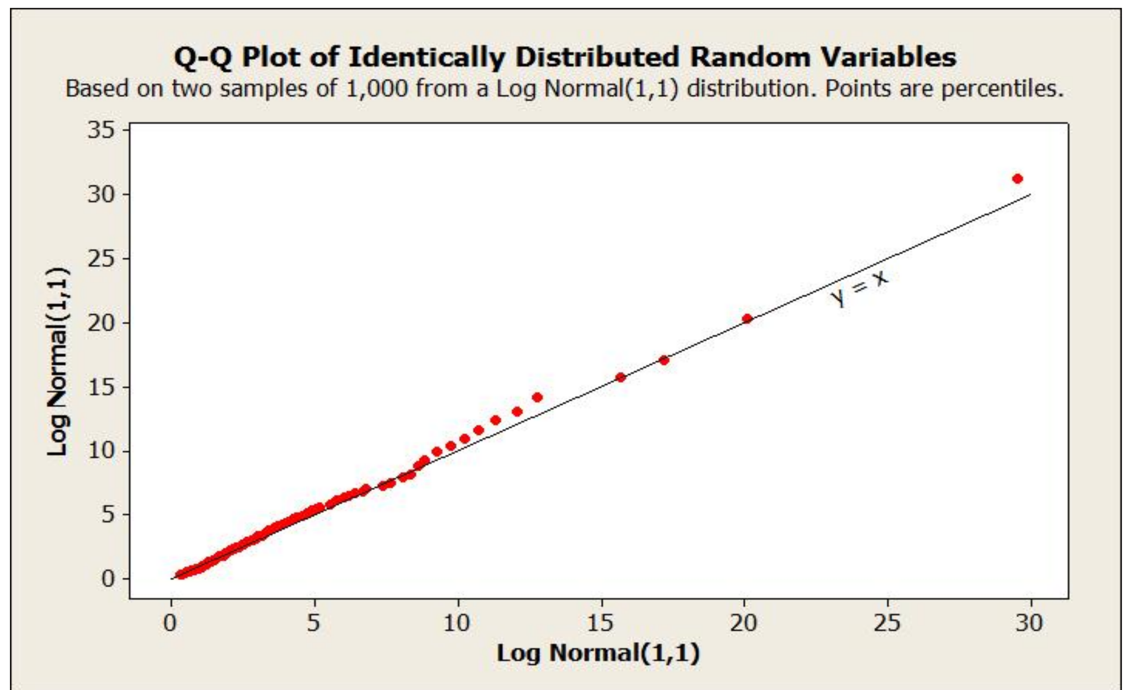
When Q-Q plots were used to investigate trends in PM2.5 and ozone, we found that different parts of the distribution behaved differently.

Exceedances are a function of the tail of the pollutant distribution. For many pollutants, this tail may decrease faster than the pollutant concentration.

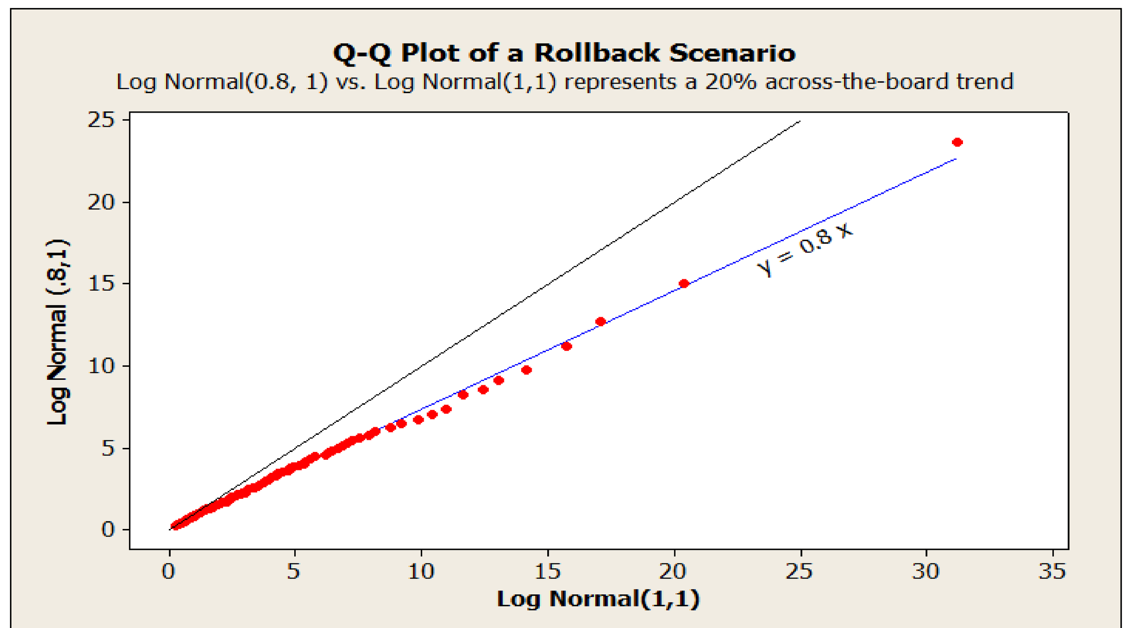
Exposure is a function the distribution of a pollutant vis-à-vis the population. If much of the population lives in areas nearly attaining the standard, then a small reduction in pollution can result in a large drop in exposure.

Q-Q Plots..

..comparing 2 variables with the same distribution will lie on the line y = x:

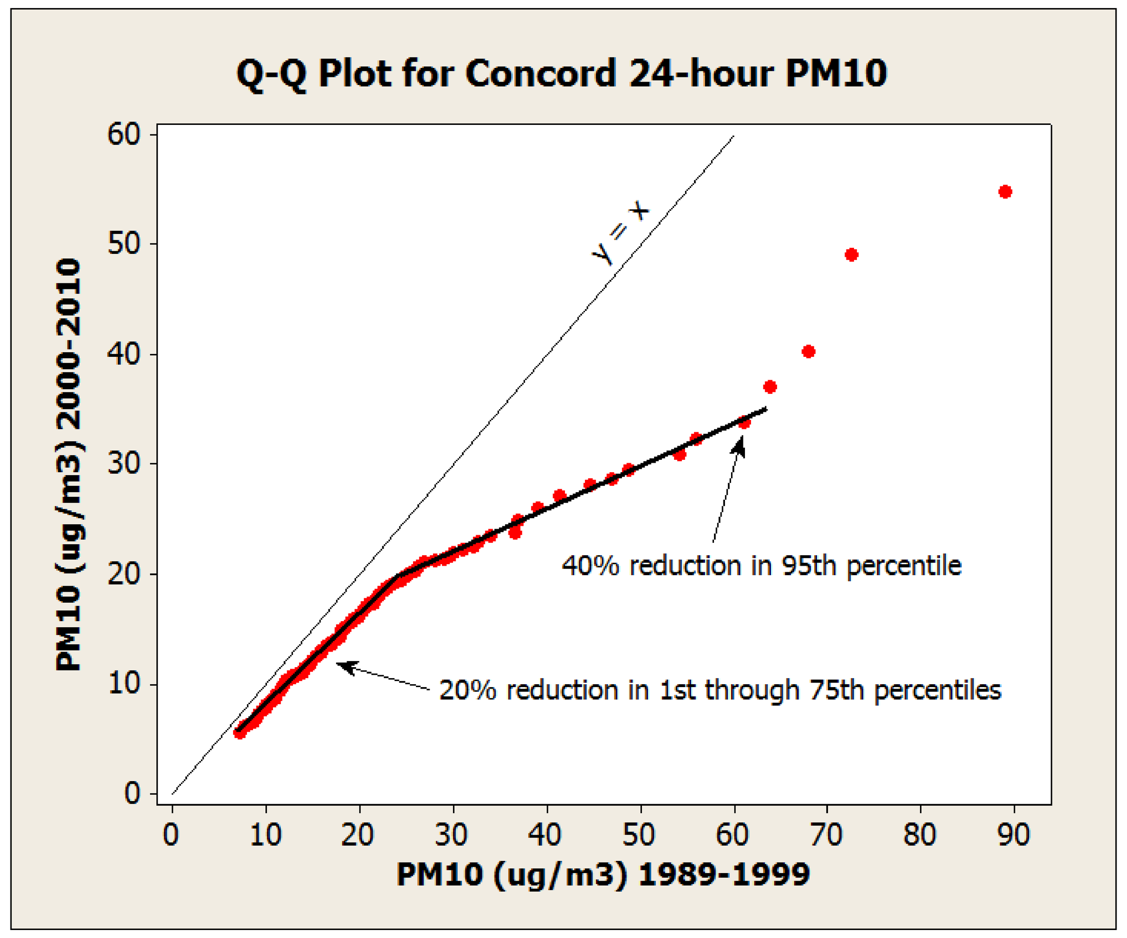


..comparing a simple rollback reduction of 100(1-k)% will lie on the line y = kx:



For PM10, Q-Q Plot Shows Steeper Reductions for Higher Percentiles

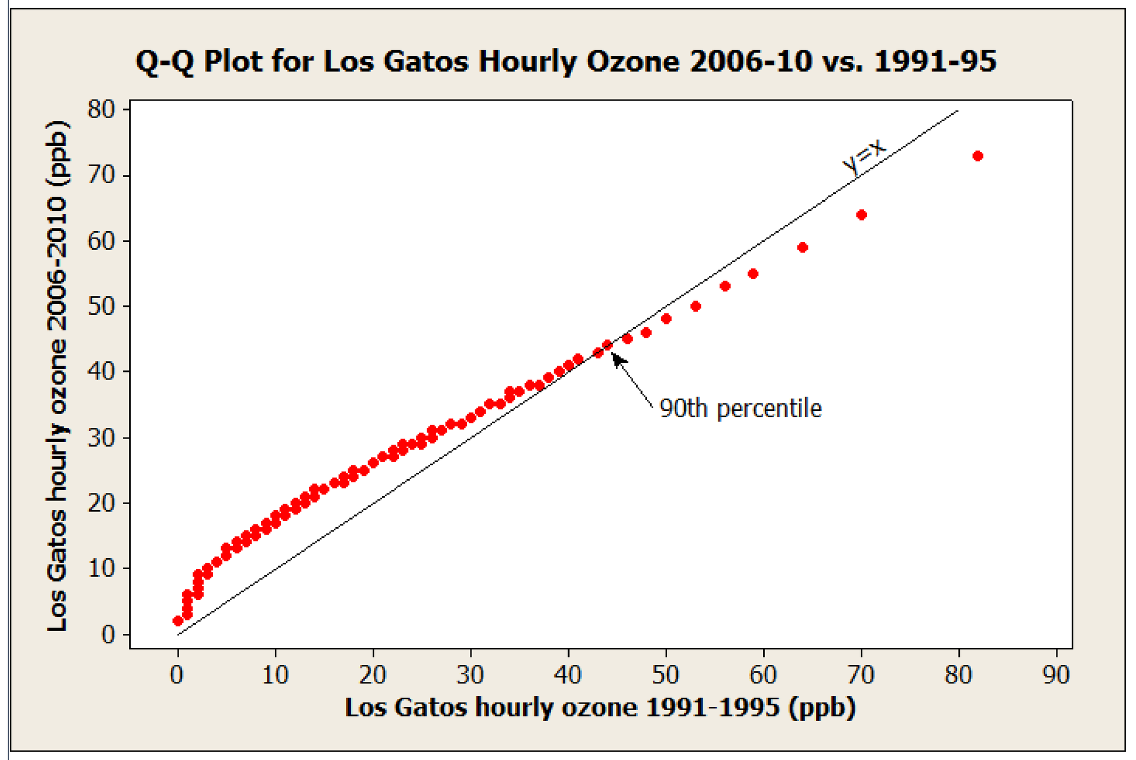
Concord PM10 shows a hockey-stick shaped trend, with reductions of about 20% in the 1st through 75th percentiles, then increased reductions up to 40% by the 95th percentile:



For Ozone, Lower Percentiles Actually Increase

The top 10% of Los Gatos hourly ozone was reduced between 1991-95 and 2006-10, but ozone actually increased for the remaining 90% of the distribution.

The cause is likely NOx titration: In the earlier decade, ozone levels were titrated far below natural background much of the time in areas near NOx sources, such as Los Gatos. Since then, NOx has been greatly reduced in the Bay Area, thereby reducing titration in source areas and allowing ozone to increase toward background.



Exceedances Tend to Drop Faster than Design Values

The number of times a pollutant exceeds a standard is proportional to the probability that the pollutant is above a certain concentration, that is, the tail of its distribution.

Concentration distributions of air pollutants frequently have exponential tails – where at high concentrations the distribution decreases exponentially. Symbolically,

$$P(X > x) = e^{-\beta x}$$

for sufficiently large x. Suppose that the high PM2.5 concentrations at a site are lowered so that X is reduced to X* = cX with 0 < c < 1. Then

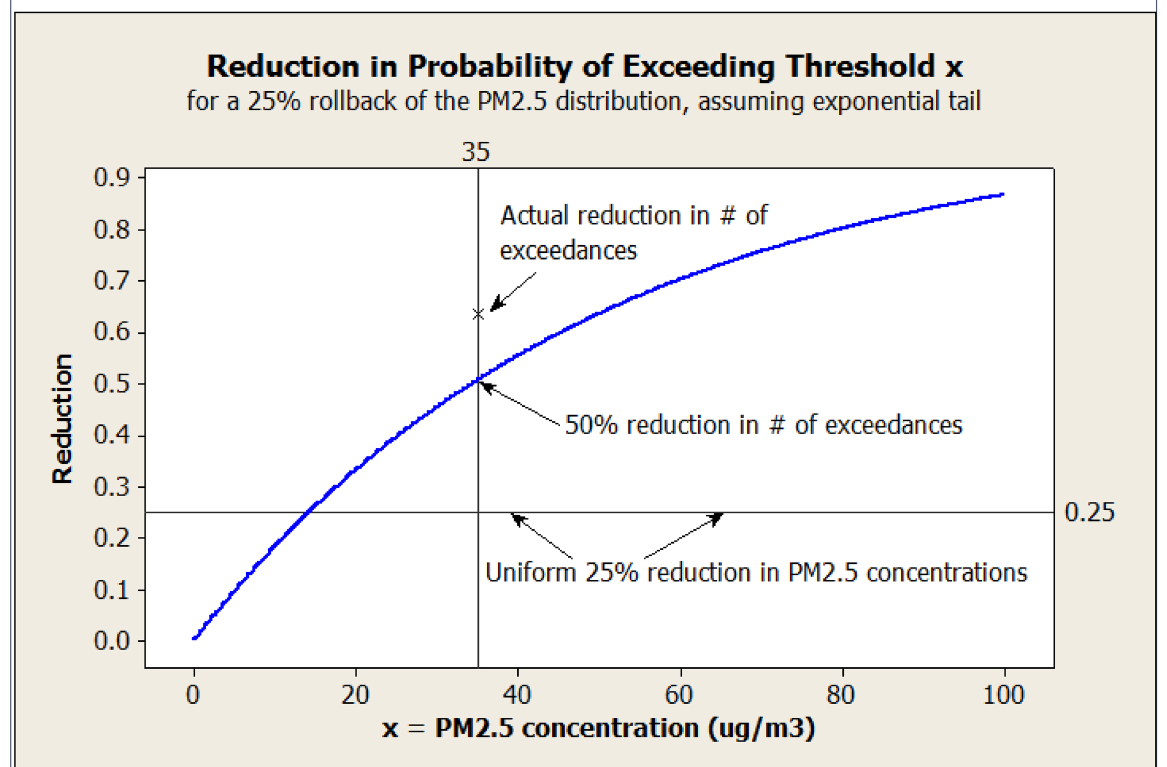
$$P(X^* > x) = (P(X > \frac{x}{c}) = e^{-\beta x/c}$$

The relative reduction in X is 1-c, whereas the reduction in the probability is

$$1 - P(X^* > x)/(P(X > \frac{x}{c}) = 1 - e^{-\beta x(\frac{1}{c} - 1)}$$

a function that gets smaller as x increases while the relative reduction in x remains 1-c. Thus, for large enough x, the reduction in probability will be greater than 1-c.

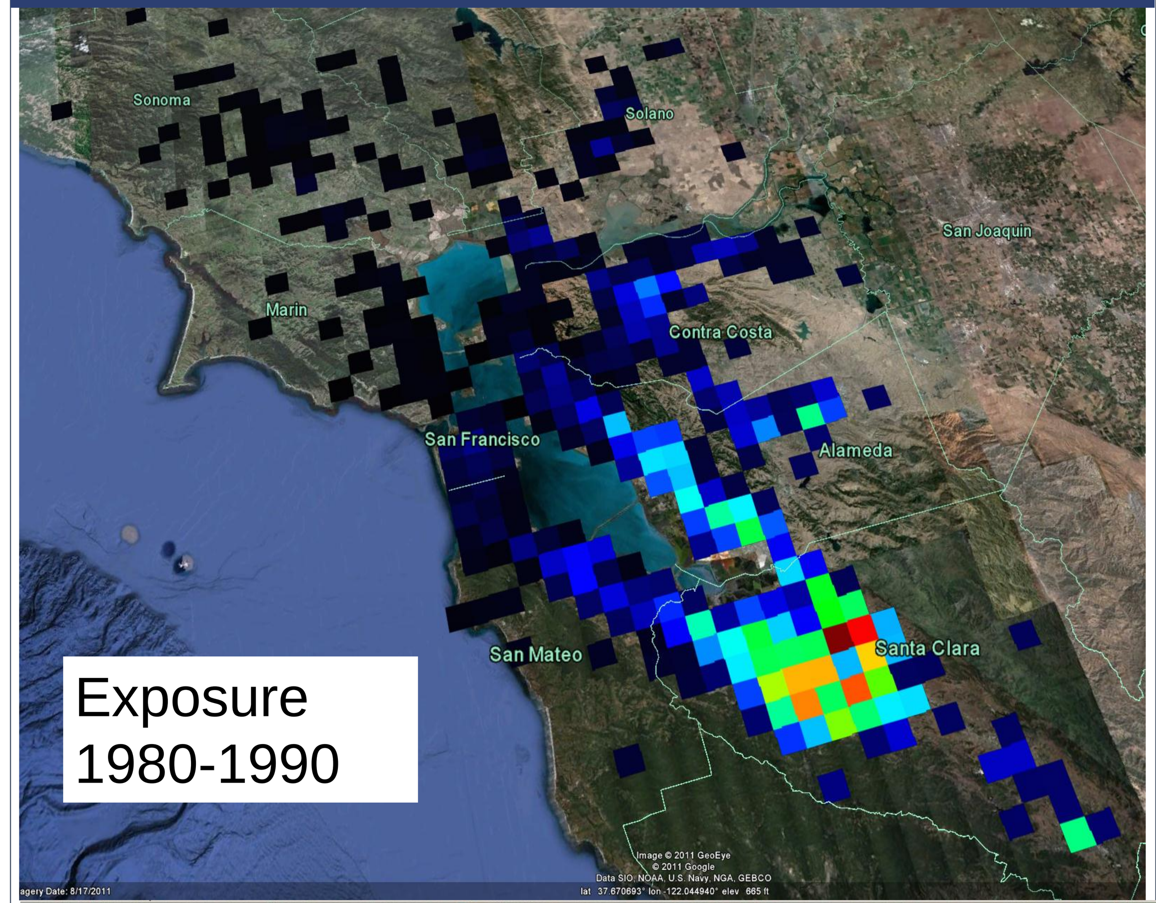
The following figure approximates the experience for San Jose PM2.5, where the design value was reduced about 25% from 2001-05 to 2006-10. In the figure, the probability of exceeding the standard is predicted to drop about 50%. (Actually, the # of exceedances dropped from 68 to 25, or 63%.)

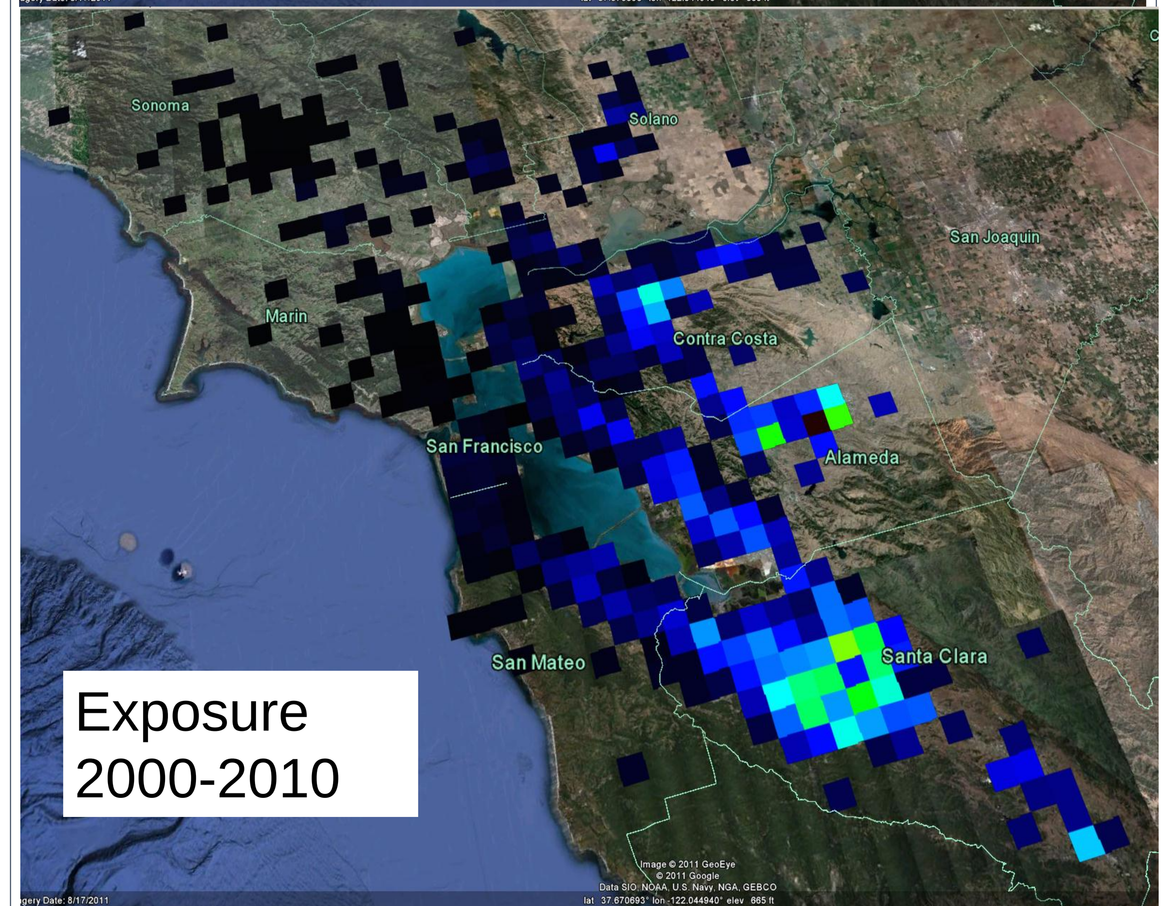


Exposure Reductions are Like an Island being Submerged

If many people live in areas that just violate a pollution standard, then a small reduction in the pollutant concentrations may result in a large reduction in exposure; just as a shallow island can be largely submerged by a small increase in sea level.

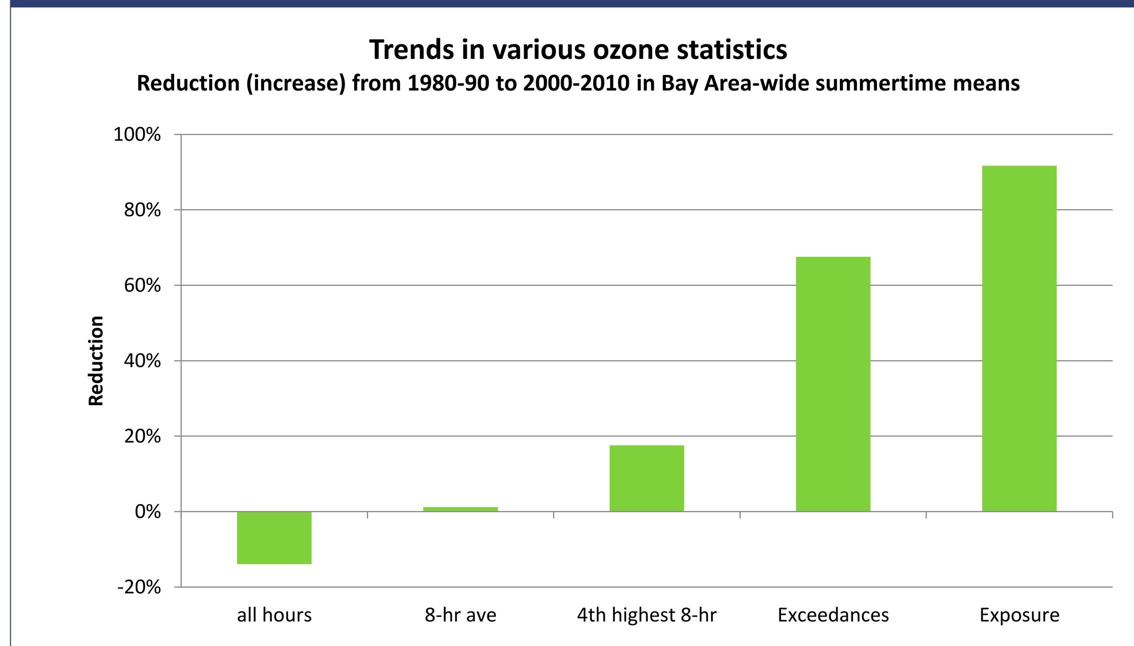
Bay Area Ozone Exposure





Figures show per capita ozone exposure: ppb-hours at or above the state 95 ppb 1-hour standard, weighted by population. Hourly ozone was interpolated to a grid from monitoring sites for all hours where some site exceeded 95 ppb.

Trends in Different Statistics



Data are hourly ozone concentrations from May-October from all Bay Area monitoring sites. The bars represent changes in the annual statistics averaged over the decades 1980-90 and 2000-2010.

All hours = all ozone concentrations from all sites.
8-hr ave = mean across days of Bay Area maximum peak 8-hour average concentration.
4^{th} highest 8-hr = 4^{th} highest of daily Bay Area maximum 8-hour peak concentrations.
Exceedances = # of days where 75 ppb standard was exceeded somewhere in the Bay Area.
Exposure = annual population-weighted ppb-hours at or above the California 95 ppb 1-hour ozone standard.